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Agricultural Memorandum No 822.

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An Approach to the Estimation of Internal Temperatures of Buildings from External Temperatures

An approach to the heat exchange between a building and its environment is indicated in the IHVE Guides. This approach uses the concept of 'sol-air temperature' as a measure of the input of radiative energy into the fabric of the building.

In a buildings without windows and working machinery, such as stores, the heat gain, Q_t, is made up of the gain through the fabric, Q_f, and the gain through ventilation, Q_v -

That is $Q_t = Q_f + Q_v$

Q_f is the sum of the products of component areas of the fabric, A_f, the thermal transmittance, U_f, of the fabric and the difference between the sol-air temperature, t_{eo}, and internal environment temperature, t_{ei}, so that

$$Q_f = A_f U_f (t_{eo} - t_{ei})$$

Q_v is given by the product of the ventilation rate, C_v, and the difference between the external and internal air temperatures, t_{ao} and t_{ai}.

$$Q_v = C_v (t_{ao} - t_{ai})$$

whence $$Q_t = A_f U_f (t_{eo} - t_{ei}) + C_v (t_{ao} - t_{ai})$$

If, after a period of time which will depend on the fabric of the building and the rate of ventilation, a steady state is reached the mean heat gain becomes zero and

$Q_t^1 = o = A_f U_f (t_{eo}^1 - t_{ei}^1) + C_v (t_{ao}^1 - t_{ai}^1)$ where the primes refer to mean values

Now $t_{eo} = t_{ao} + R_{so} (\alpha I_t - \epsilon I_L)$ as defined by equation A 6.4 in the IHVY Guide where

R_{so} is the external surface resistance.
α is the absorption coefficient applying to the outer surface of the wall or roof.
I_t is the intensity of direct plus diffuse solar radiation on the outer surface.
ϵ is the emmivity of the outer surface to long wave radiation.
I_l is the intensity of longwave radiation from a black surface at air temperature.

The term $R_{so} (\alpha I_t - \epsilon I_L)$ is referred to as the 'sol-air temperature increment' and for the sake of brevity be referred to as TI. The IHVE Guide contains tables giving values for the term. It appears from inspection of the tables that $t^I_{eo} = t^I_{ao} + (TI)^I$ and this relationship may be used to simplify the algebra.

$$\Sigma A_f U_f (t'_{eo} - t'_{ai}) + C_v (t'_{ao} - t'_{ai}) = 0$$

or $$\Sigma A_f U_f \left[t'_{ao} + (TI)' - t'_{ei}\right] + C_v (t'_{ao} - t'_{ai}) = 0$$

$$(\Sigma A_f U_f + C_v) t'_{ao} + \Sigma A_f U_f (TI)' - \Sigma A_f U_f t'_{ei} - C_v t'_{ai} = 0$$

or $$\Sigma A_f U_f t'_{ei} + C_v t'_{ai} = \left(\Sigma A_f U_f + C_v\right) t'_{ao} + \Sigma A_f U_f (TI)'$$

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In the context that a steady state has been reached t'_{ei} will be almost the same as t'_{ai}, though the Guides do not say so but in chapter 5 the terms appear to have been interchanged in one instance

putting $t'_{ei} = t'_{ai}$ $\quad \left(\sum A_f U_f + C_v\right) t'_{ei} = \left(\sum A_f U_f + C_v\right) t'_{ao} + \sum A_f U_f (TI)'$

$$t'_{ei} = \frac{\left(\sum A_f U_f + C_v\right) t'_{ao} + \sum A_f U_f (TI)'}{\left(\sum A_f U_f + C_v\right)}$$

$$t'_{ei} = t'_{ao} + \frac{\sum A_f U_f (TI)'}{\left(\sum A_f U_f + C_v\right)}$$

Data concerning $(TI)'$ are included in Table I at the end. When rates of ventilation are low ie less than 2 changes per hour.

$C_v \doteq 0.33$ Nv where v is the volume of the building and

N is the number of air changes per hour

N will be composed of the number of changes due to natural ventilation and changes due to forced ventilation.

For higher rates of ventilation C_v may be obtained from the expression

$$\frac{1}{C_v} = \frac{1}{0.33Nv} + \frac{1}{4.8\Sigma A}$$

where A is the total area bounding the enclosure (IHVE Guide A8.6).

The foregoing indicates a method of obtaining mean internal temperatures from external temperatures and radiation. For the upper limits of temperature the following method is suggested, following Chapter A.8 which deals with 'swings' of various quantities from mean to extreme values. The 'tilde' type symbol is used to signify the value of the 'swing' of a quantity from its mean value to its maximum.

$$\tilde{Q}_t = \tilde{Q}_s + \tilde{Q}_f + \tilde{Q}_c + \tilde{Q}_a \qquad \text{(A.8.11)}$$

where $\tilde{Q}_s$ is the swing in effective heat gain due to soliar radiation through glass
$\tilde{Q}_f$ is the swing in effective heat input due to structural gain
$\tilde{Q}_c$ is the swing in effective heat gain due to casual gains (lights, persons, machines)
$\tilde{Q}_a$ is the swing in effective heat input due to swing in outside temperature

In the context of stores and sealed buildings without windows, $\tilde{Q}_s$ and $\tilde{Q}_c$ may be neglected, and $\tilde{Q}_t = \tilde{Q}_f + \tilde{Q}_a$.

Now $\tilde{Q}_f = \sum f A_f U_f \left(t_{eo} - t'_{ac}\right)$ where f is the decrement factor dependent on the type and thickness of wall or roof and here t_{eo} is the sol-air temperature at the time of peak input.

$\tilde{Q}_a = \left(\sum A_g U_g + C_v\right) \tilde{t}_{ao}$ (where the suffix g refers to glass)

Again, if there are no windows $\sum A_g U_g = 0$

So that $\tilde{Q}_t = \sum f A_f U_f \left(t_{eo} - t'_{ao}\right) + C_v \tilde{t}_{ao}$

The magnitude of the swing in internal temperatures may be determined by the use of

admittance values, Y, and the following expression.

$$\tilde{Q} = \left(\Sigma AY + C_v\right)\tilde{t}_{ei}$$

Thus $$\left(\Sigma AY + C_v\right)\tilde{t}_{ei} = \Sigma f A_f U_f \left(t_{ec} - t'_{ec}\right) + C_v \tilde{t}_{ao}$$

or $$\tilde{t}_{ei} = \frac{\Sigma f A_f U_f \left(t_{ec} - t'_{ec}\right) + C_v \tilde{t}_{ao}}{\Sigma AY + C_v}$$

The expression $\Sigma f A_f U_f \left(t_{ec} - t'_{ec}\right) + C_v \tilde{t}_{ao}$ may be manipulated as before so that

it becomes $$\Sigma f A_f U_f \left[t_{ao} + TI - t'_{ao} - (TI)'\right] + C_v \tilde{t}_{ao}$$

$$\Sigma f A_f U_f \left(t_{ao} - t'_{ao}\right) + \Sigma f A_f U_f \left[TI - (TI)'\right] + C_v \tilde{t}_{ao}$$

or $$\left(\Sigma f A_f U_f + C_v\right)\tilde{t}_{ao} + \Sigma f A_f U_f \left(\tilde{TI}\right)$$

and $$\tilde{t}_{ei} = \frac{\left(\Sigma f A_f U_f + C_v\right)\tilde{t}_{ao} + \Sigma f A_f U_f \left(\tilde{TI}\right)}{\Sigma AY + C_v}$$

where $\tilde{t}_{ao} = \left(t_{ao} - t'_{ao}\right)$ and $\left(\tilde{TI}\right) = TI - (TI)'$

$TI - (TI)^1$ is the swing in sol-air temperature increment, and figures for this component have been evaluated and are shown in Table III.

t_{ei} (max) may be deduced from the expression

$$t_{ei}\ (\max) = t^1_{ei} + t_{ei}.$$

In the above expression t_{ao} is the outside air temperature at the time of maximum input of heat into the building and is not necessarily the same as the maximum air temperature because the time of maximum heat input depends on the shape and orientation of the building. The approximate solar times of maximum heat input into buildings of various shapes and orientations are listed in Table II.

Examination of Table II leads to the suggestion that for most buildings the error involved in assuming that t_{ao} and the maximum air temperature are the same will fall within acceptable limits. In view of some of the other assumptions and simplifications implicit in the IHVE guide data this does not seem to be an unreasonable assumption However, if hourly temperatures are available the appropriate ones should be used.

With regard to the effects of the wind it should be noted that the terms R_{so}, U and C_v all have a factor which takes account of the wind. The IHVE guides use the terms sheltered, standard and severe for the exposure of buildings. In the Guides the tabulated values of sol-air temperature are based on the so called 'standard' exposure which assumes a wind speed in the range 4 to 5.5 ms $^{-1}$. Table IV shows the values of R_{so} for different exposures and materials. The IHVE guide states in chapter A6 that values of R_{so} used for the calculation of tables A.6.15 to A.6.22 were 0.05 for walls and 0.04 for roofs. Table V shows the ratio between these values - taken as 1 - and the other values in table IV. These ratios should permit simple adjustments to be made to the figures for TI and its 'swing' which are shown in Tables I and III.

The calculation of the fraction of N_v in the expression $C = \frac{n}{V} = .333 N N_v$ attributable to leaks through cracks and unsatisfactory seals may be accomplished in the manner outlined in IHVE guide chapter A.4. Table VI lists some values for N.

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December 1977

APPENDIX

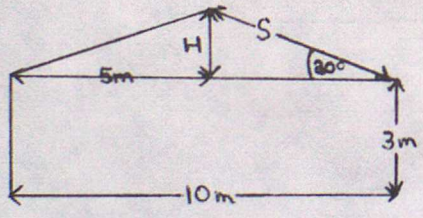
The use of the formulae is best illustrated by working through the following examples.

EXAMPLE 1

An estimate is required of the mean and maximum internal temperatures in a rectangular building on an exposed site during a windy period in mid March. The walls are of 220 mm brick with a covering of lightweight plaster on the inside. The long sides face SE and NW. The roof has a 20° slope, and is constructed of corrugated asbestos sheeting with a cavity and aluminium foil backed 10 mm plasterboard lining. The doors and shutters fit poorly and the external surfaces have collected enough dust for them to be classed as dark for radiation purposes. The dimensions of the building are length 20 metres, breadth 10 metres, walls 3 metres high at the eaves and 4.8 metres at the ridge.

	Information Required	How Obtained
A_f	surface areas of exposed walls and roofs.	Calculated from dimensions given.
	volume of building.	ditto
U_f	U values for materials of walls and roofs.	I.H.V.E guide or Buildings Adviser.
Y	Y, admittances, for materials of walls and roofs.	ditto
f	Decrement factor for roofs and walls.	ditto
t'_{ao}	Mean external air temperature.	) Either from records kept locally or) from estimates obtained from the) Meteorological Office - either HQ or) one listed in PO guide.
t_{ao} (max)	External air temperature at time of maximum heat input.	

In this example it is assumed the appropriate values are 5° and 10°C so that $\tilde{t}_{ao}$ = 10-5 = 5°C.



H = 5 tan 20 = 1.8 m
S = 5 sec 20 = 5.3 m

A_f

SE and NW walls:	each 20 m x 3 m	=	60 m^2
SW and NE walls:	each 10 m x 3 m + $\frac{1}{2}$ (10 m x 1.8 m)	=	39 m^2
Sloping roof :	each face 20 m x 5.3 m	=	106 m^2
Volume of building	39 m^2 x 20 m	=	780 m^3

End Wall, SW or NE.

The mean internal temperature is given by

$$t'_{ei} = t'_{ao} + \frac{\sum A_f U_f (TI)'}{(\sum A_f U_f + C_v)}$$

t'_{ao} in this example is given as 5°C, and the other quantities are calculated as follows.

Values of $A_f U_f$ (TI)' are required for each face and then they must be added together.

The site is given as exposed and the period as windy, so (TI)' values must be adjusted by the factors given in Table V. Dark surfaces are taken to have high emissivity so that the required factors are 0.6 for the walls and 0.5 for the roof. (TI)' values are taken from Table I - for March - and multiplied by the appropriate A_f and U_f values and the reduction of factors.

	A_f		U_f			(TI)'		$A_f U_f$ (TI)'
SE Wall	60	x	2.0	=	120	x 0.6	x 7.8	= 562
NW Wall	60	x	2.0	=	120	x 0.6	x 2.3	= 166
SW Wall	39	x	2.0	=	78	x 0.6	x 7.8	= 365
NE Wall	39	x	2.0	=	78	x 0.6	x 2.3	= 108
SE Roof	106	x	2.0	=	212	x 0.5	x 3.2	= 329
NW Roof	106	x	2.0	=	212	x 0.5	x 0.4	= 42
			$\sum A_f U_f$	=	820		$\sum A_f U_f$(TI)'	= 1282

Note: The U values used here have been taken from IHVE guide, Chapter A3, Table 10.1 for the wall, Table 14.5 for the roof. (It is coincidence that the values are the same.)

$C = 0.33\ N V$. $V = 780\ m_3$ and from Table VI $N = \frac{3}{4}$ for volumes between 300 and 3,000 m^3 for single storey of unpartitioned buildings.

$$C = 0.33 \times \tfrac{3}{4} \times 780 = 195$$

$$t'_{ei} = 5 + \frac{1282}{820 + 195} = 5 + \frac{1282}{1015} = 5 + 13 = 6.3$$

The mean internal temperature is estimated to be 6.3°C.

The swing in internal temperature is given by

$$\tilde{t}_{ei} = \frac{(\Sigma f A_f U_f + C_v)\tilde{t}_{ao} + \Sigma f A_f U_f (\tilde{TI})}{\Sigma AY + C_v}$$

$\tilde{t}_{ao} = 5°$ in this example; C_v from the foregoing is 195, f for the materials specified is 0.5 for the walls and 0.9 for the roof. From chapter A.8 of IHVE guides.

From Table II the time of maximum heat input into a building with its long sides facing SE and NW is 1200 Solar time in March so that values for (TI) are taken from Table III.

	f	A_f	U_f		$f A_f U_f$		$(\widetilde{TI})$		$f A_f U_f (\widetilde{TI})$
SE Wall	0.5	x 120		= 60	x 0.6	x	16.5	=	594
NW Wall	0.5	x 120		= 60	x 0.6	x	2.1	=	76
SW Wall	0.5	x 78		= 39	x 0.6	x	16.5	=	386
NE Wall	0.5	x 78		= 39	x 0.6	x	2.1	=	49
SE roof	0.9	x 212		= 191	x 0.5	x	17.3	=	1650
NW roof	0.9	x 212		= 191	x 0.5	x	9.6	=	917
	$\Sigma f A_f U_f$			= 580	$\Sigma f A_f U_f (\widetilde{TI})$				3672

	A	Y	AY
SE & NW Walls	2 x 60	x 5.0	= 600
SW & NE Walls	2 x 39	x 5.0	= 390
Roof	2 x 106	x 3.0	= 636
	Σ AY		= 1626

Suitable values for Y may be obtained from IHVE Guide Chapter 8 in most cases.

$$\widetilde{t}_{ei} = 5\,\frac{(580 \times 195) + 3672}{1626 + 195} = \frac{5 \times 775 + 3672}{1821} = \frac{3875 + 3672}{1821} = \frac{7547}{1821}$$

$$t_{ei}(max) = t'_{ei} + \widetilde{t}_{ei} = 6.3 + 4.1 = 10.4^{o}C$$

EXAMPLE 2

An estimate is required of mean and maximum internal temperatures in a building of similar dimensions and structure to those in example 1, but the external surfaces are clean and light and of low emissivity, the site is sheltered and the long sides face north and south.

The period is June.

Assume the mean daily temperature to be 16°C and the temperature at time of maximum heat input into the building to be 24°C ie $\widetilde{t}_{ao}$ = 24-16 = 8°C.

Proceeding as before:-

	A_f		U_f		A_fU_f	TABLE V	$(TI)'$	$A_fU_f(TI)'$
South Wall	60	x	1.8	=	108	x 2.2	x 3.9	= 926
North Wall	60	x	1.8	=	108	x 2.2	x 2.3	= 546
East Wall	39	x	1.8	=	70	x 2.2	x 4.7	= 724
West Wall	39	x	1.8	=	70	x 2.2	x 4.6	= 708
South Roof	106	x	1.8	=	191	x 2.25	x 2.9	= 1246
North Roof	106	x	1.8	=	191	x 2.25	x 2.1	= 902
			ΣA_fU_f	=	738		$\Sigma A_fU_f(TI)'$	5052

Again, it is coincidence that the U values are the same for roof and walls.

$$t'_{ei} = 16 + \frac{5052}{738 + 195} = 16 + \frac{5052}{933} = 16 + 5.4 = 21.4^{\circ}C$$

The mean internal temperature is estimated to be 21.4°C.

The swing in internal temperature follows as before.

Time of maximum solar input 1400 Solar time - Table II.

	f		A_fU_f		fA_fU_f	TABLE V	$(\widetilde{TI})$	$fA_fU_f(\widetilde{TI})$
South Wall	0.5	x	108	=	54	x 2.2	x 6.8	= 808
North Wall	0.5	x	108	=	54	x 2.2	x 0.9	= 107
East Wall	0.5	x	70	=	35	x 2.2	x - 1.5	= - 115
West Wall	0.5	x	70	=	35	x 2.2	x 7.8	= 601
South Roof	0.9	x	191	=	172	x 2.25	x 9.7	= 3710
North Roof	0.9	x	191	=	172	x 2.25	x 6.1	= 2360
			ΣfA_fU_f	=	522		$\Sigma fA_fU_f(\widetilde{TI})$	= 7471

	A	Y	AY
South and North Walls	2 x 60	x 5.0 =	600
East and West Walls	2 x 39	x 5.0 =	390
Roof	2 x 106	x 3.0 =	636
	ΣAY	=	1626

$$\widetilde{t}_{ei} = \frac{8(522 + 195) + 7471}{1626 + 195} = \frac{8 \times 717 + 7471}{1821} = \frac{5736 + 7471}{1821}$$

$$= \frac{13207}{1821} = 7.3$$

$$t_{ei}\ (max) = t'_{ei} + \widetilde{t}_{ei} = 21.4 + 7.3 = 28.7^{\circ}C$$

EXAMPLE 3

An estimate is required of the mean and maximum internal temperatures in a cylindrical store with a conical roof, constructed of steel sheeting which has become dark. It is situated in a sheltered position and the period of interest is a warm sunny spell in mid-August. The diameter of the store is 8 metres and its height 20 metres and the base angle of the cone shaped roof is 27°.

It is assumed that $t'_{ao} = 16°C$, t_{ao} (max) $= 24°C$ therefore $\tilde{t}_{ao} = 8°C$.

The surface area of a cylinder is given by π x diameter x height ($2\pi rh$) = 160 x π = 534 m^2. The surface area of a cone is given by $\pi r\sqrt{r^2+h^2}$. In the case of a cone of base angle 27°, $h = \frac{1}{2}r$, and the expression becomes $\pi r^2\sqrt{\frac{5}{4}}$. With diameter 8 metres, r is 4 metres and the surface area becomes $8\pi\sqrt{5}\ m^2 = 56.2\ m^2$.

Volume of the cylinder is $\pi \times (\text{radius})^2$ x height = 320π = 1005 m^3.

Volume of the cone is $\frac{1}{3} \times \pi \times (\text{radius})^2$ x height of cone = $\frac{1}{3}\pi r^2 \times \frac{1}{2}r$ = 176 r^3 = 33.5 m^3.

Volume of the building is 1038.5 m^3.

This type of structure is alleged to be sealed in which case N = 0 and therefore C_v would be zero. However, it may be instructive to compare the case of zero ventilation with the case of N = 1½ as given in table VI. C_v would then be 0.33 x 3/2 x 1038.5 = 514.

As before -

	A_f	U_f	A_fU_f	From Table V (TI)'	$A_fU_f(TI)'$
Cylinder	534 x	5.0 =	2670	x 1.6 x 6.4 =	27330
Cone	56 x	5.7 =	319	x 1.75 x 5.1 =	2850
	ΣA_fU_f	=	2989	$\Sigma A_fU_f(TI)'$ =	30180

$$t'_{ei} = 16 + \frac{30180}{2989 + 514} = 16 + \frac{30180}{3503} = 16 + 8.6 = \underline{24.6°C}.$$

if ventilation is zero then $t'_{ei} = 16 + \frac{30180}{2989} = 16 + 10.1 = \underline{26.1°C}$.

For the swing in internal temperature.

The time of maximum heat input is 1400 Solar time = Table II, Cylinder, August.

	f	A_fU_f	fA_fU_f	$(\tilde{TI})$	$fA_fU_f(\tilde{TI})$
Cylinder	0.9 x	2670 =	2403	x 1.6 x 6.7 =	25,750
Cone	0.9 x	319 =	287	x 1.75 x 13.5 =	6,790
	$\Sigma f A_fU_f$	=	2690	$\Sigma fA_fU_f(\tilde{TI})$ =	32,540

	A		Y*		AY
Cylinder	534	x	5.0	=	2670
Cone	56	x	5.7	=	319
	Σ AY			=	2989

*Values of Y for relatively thin unlined metal structures are not published in IHVE guides, but a telephone conversation with the Information Section of the Building Research Station elicited the suggestion that for such metal structures the Y values would be approximately the same as U values.

$$\tilde{t}_{ei} = \frac{8 \times 2690 + 32540}{2989 + 514} = \frac{21520 + 32540}{3503} = \frac{54060}{3503} = 15.6^{\circ}C$$

or if $C_v = 0$ $\quad \tilde{t}_{ei} = \frac{54060}{2989} = 18.9^{\circ}C$

t_{ei} (max) = 24.6 + 15.6 = $\underline{40.2^{\circ}C}$ or if ventilation is zero 26.1 + 18.9 = $\underline{45.0^{\circ}C}$.

For a similar structure under the conditions of so-called normal and severe exposures the arithmetic becomes -

For Normal Exposure

	A_f	U_f	A_fU_f	$(TI)'$	$A_fU_f(TI)'$
Cylinder	534 x	5.7 =	3045	x 6.4 =	19500
Cone	56 x	6.7 =	375	x 5.1 =	1913
	ΣA_fU_f =		3420	$\Sigma A_fU_f(TI)'$ =	21413

$$t'_{ei} = 16 + \frac{21413}{3420 + 514} = 16 + \frac{21413}{3834} = 15 + 5.4 = \underline{21.4^{\circ}C}$$

or without ventilation

$$t'_{ei} = 16 + \frac{21413}{3420} = 16 + 6.3 = \underline{22.3^{\circ}C}.$$

For Severe Exposure

	A_f	U_f	A_fU_f	$(TI)'$	$A_fU_f(TI)'$
	534 x	6.6 =	3,525	x 0.6 x 6.4 =	13,540
	56 x	8.1 =	454	x 0.5 x 5.1 =	1,157
	ΣA_fU_f =		3,979	$\Sigma A_fU_f(TI)'$ =	14,697

$$t'_{ei} = 16 + \frac{14697}{3979 + 514} = 16 + \frac{14697}{4493} = 16 + 3.3 = \underline{19.3^{\circ}C}$$

or without ventilation

$$t'_{ei} = 16 + \frac{14697}{3979} = 16 + 3.7 = \underline{19.7^{\circ}C}.$$

The swing in temperature in these cases would be -

Normal Exposure

	f	A_fU_f	fA_fU_f	$(\tilde{TI})$	$fA_fU_f(\tilde{TI})$
Cylinder	0.9 x	3045 =	2740	x 6.7 =	18350
Cone	0.9 x	375 =	337	x 13.5 =	4550
	ΣfA_fU_f =		3077	$\Sigma fA_fU_f(\tilde{TI})$	22900

Severe Exposure

	f	A_fU_f	fA_fU_f	$(\tilde{TI})$	$fA_fU_f(\tilde{TI})$
	0.9 x	3525 =	3173	x 0.6 x 6.7 =	12760
	0.9 x	454 =	409	x 0.5 x 13.5 =	2760
	ΣA_fU_f =		3582	$\Sigma fA_fU_f(\tilde{TI})$ =	15520

$\tilde{t}_{ei} = \frac{8 \times 3077 + 22900}{3077 + 514} = \frac{47516}{3591} = 13.2^{o}C$

when $t_{ei}(max) = 21.4 + 13.2 = \underline{34.6^{o}C}$

or if ventilation is zero

$\tilde{t}_{ei} = \frac{47516}{3077} = 15.5$

and $t_{ei}(max) = 22.3 + 15.5 = \underline{37.8^{o}C}$

$\tilde{t}_{ei} = 8 \times \frac{3582 + 15520}{3582 \times 514} = \frac{44176}{4096} = 10.8^{o}C$

$t_{ei}(max) = 19.3 + 10.8 = \underline{30.1^{o}C}$

$\tilde{t}_{ei} = \frac{44176}{3581} = 12.3$

$t_{ei}(max) = 19.7 + 12.3 = \underline{32.0^{o}C}$

EXAMPLE 4

The results of some measurements in steel containers are reported in the 'Marine Observer' Vol XLVII No 258, October 1977. The containers are described as 20 ft - presumably cubes - and were painted yellow. The measurements shown in detail refer to 6 September 1971 at Hamburg Container Terminal. "For a light northerly wind ..... an ambient air temperature of 20.3°C contrasted with the temperatures of 41.0°C just beneath the ceiling and 34.6°C in the interior". From the diagram (Fig 4)* the maximum and minimum outside air temperatures were 20°C and 10°C giving a mean air temperature of 15°C and $\tilde{t}_{ao}$ 5°C.

Twenty feet is approximately 6 metres: it will be assumed that the orientation is towards the cardinal points of the compass.

Calculations will be done for Dark and Light Surfaces and for Sheltered and Normal Exposures.

There is no ventilation so $C_v = 0$.

Normal Exposure

	A U AU	(TI)' Dark Material
N Face	36 x 5.7 = 205	x 1.5 = 307
S Face	36 x 5.6 = 205	x 9.2 = 1865
E Face	36 x 5.7 = 205	x 5.0 = 1025
W Face	36 x 5.7 = 205	x 5.0 = 1025
Top	36 x 6.7 = 242	x 2.4 = 581
	Σ AU =1062	Σ AU(TI)' 4803

AU x (TI)' Light Material	
0.8 =	164
5.0 =	1025
2.8 =	574
2.8 =	574
- 0.2 =	- 48
Σ AU(TI)' =	2289

$t'_{ei} = 15 + \frac{4803}{1062} = 15 + 4.5 = 19.5^{o}C$

$t'_{ei} = 15 + \frac{2289}{1062} = 15 + 2.2 = 17.2^{o}C$

*not reproduced here

The swing in temperature is given by:-

	f	AU	fAU		$(\widetilde{TI})$ Dark Material	fAU x $(\widetilde{TI})$ Light Material
N Face	0.9 x 205 =	184.5	x	2.6 =	480	1.4 = 258
S Face	0.9 x 205 =	184.5	x	17.1 =	3152	9.5 = 1750
E Face	0.9 x 205 =	184.5	x	- 1.0 =	185	- 0.6 = - 111
W Face	0.9 x 205 =	184.5	x	15.5 =	2860	8.6 = 1586
Top	0.9 x 242 =	218	x	10.3 =	2245	6.2 = 1351
	Σ fAU	= 956	Σ fAU$(\widetilde{TI})$	=	8552	Σ fAU$(\widetilde{TI})$ = 4834

If V = U then ΣAV = ΣAU and

$$\widetilde{t}_{ei} = \frac{5 \times 956 + 8552}{1062} = \frac{4780 + 8552}{1062} = \frac{13332}{1062} = 12.5.$$

$$\widetilde{t}_{ei} = \frac{4780 + 4834}{1062} = \frac{9614}{1062} = 9.1.$$

t_{ei} (max) = 19.5 + 12.5 = 32.0°C.

t_{ei} (max) = 17.2 + 9.1 = 26.3°C.

Sheltered Exposure

	A	U	AU	Table V	(TI)' Dark Material	AU x Table V x (TI)' Light Material
N Face	36 x 5.0 =	180	x 1.6	x 1.5 =	432	2.2 x 0.8 = 317
S Face	36 x 5.0 =	180	x 1.6	x 9.1 =	2620	2.2 x 5.0 = 1980
E Face	36 x 5.0 =	180	x 1.6	x 5.0 =	1440	2.2 x 2.8 = 1110
W Face	36 x 5.0 =	180	x 1.6	x 5.0 =	1440	2.2 x 2.8 = 1110
Top	36 x 5.7 =	205	x 1.75	x 2.4 =	862	2.25 x - 0.2 = - 92
	ΣAU	= 925	ΣAU(TI)'	=	6794	ΣAU(TI)' = 4425

$$t'_{ei} = 15 + \frac{6794}{925} = 15 + 7.3 = 22.3°C$$

$$t'_{ei} = 15 + \frac{4425}{925} = 15 + 4.6 = 19.6°C$$

The swing in temperature is given by -

	f	AU	fAU		$(\widetilde{TI})$	Dark Material	fAU x $(\widetilde{TI})$	Light Material
N Face	0.9 x 180 =	162	x 1.6	x	2.6	674	2.2 x 1.4 =	500
S Face	0.9 x 180 =	162	x 1.6	x	17.1	4440	2.2 x 9.5 =	3390
E Face	0.9 x 180 =	162	x 1.6	x -	1.0 = -	259	2.2 x - 0.6 = -	214
W Face	0.9 x 180 =	162	x 1.6	x	15.5 =	4020	2.2 x 8.6 =	3065
Top	0.9 x 205 =	184.5	x 1.75	x	10.3 =	3325	2.25 x 6.2 =	2575
	Σ fAU	= 832.5	Σ fAU$(\widetilde{TI})$			= 12,200	Σ fAU$(\widetilde{TI})$	= 9316

$$\widetilde{t}_{ei} = \frac{5 \times 832.5 + 12200}{925} = \frac{4163 + 12200}{925} = \frac{16363}{925} = 17.7°C$$

$$\widetilde{t}_{ei} = \frac{4163 + 9316}{925} = \frac{13479}{925} = 14.6°$$

$t_{ei}(max) = 22.3 + 17.7 = \underline{41.0^{o}C}.$ $t_{ei}(max) = 19.6 + 14.6 = \underline{34.2^{o}C}.$

The figure of $34.2^{o}C$ for a light material in a sheltered situation is in astonishingly close agreement with the value of $34.6^{o}C$ quoted in the article. It is in fact rather too good to be true considering that the f and U values for the casing are unknown but it is felt that the method is capable of producing answers of the right order of magnitude.

For the temperature just under the roof, the maximum would occur just after mid-day solar time. Using the figures for a light surface and the mean internal temperature derived above we have:-

$AU = 205$ $fAU = 184.5$ $\widetilde{(TI)} = 7.8 \times 2.25$ (for sheltered situation Table V)

$fAU\ \widetilde{(TI)} = 3240$

$t_{ei}^{i} = 19.6^{o}C$ $\tilde{t}_{ei} = \frac{3240 + 184.5 \times 5}{205} = \frac{4165}{205} = 20.3^{o}C,$

$t_{ei}(max) = 19.6 + 20.3 = \underline{39.9^{o}C}$ compared with the measured value of $41^{o}C$. Again the figure is of the right order.

Any comments or suggestions about this paper should be addressed to the author.

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Table I

Mean Sol-air Temperature Increments (TI)[1] for walls of various aspects, horizontal surfaces, a cylindrical surface and conical and hemispherical caps

Dark and Light coloured materials

	North		East		South		West		Horizontal	
	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light
16 January	0.5	0.3	1.5	0.9	5.5	3.1	1.5	0.9	- 2.0	- 2.8
15 February	0.8	0.5	2.7	1.5	7.6	4.2	2.7	1.5	- 0.6	- 1.9
22 March	1.4	0.8	5.0	2.8	9.1	5.0	5.0	2.8	2.3	- 0.2
20 April	2.0	1.2	6.8	3.8	8.6	4.8	6.8	3.8	5.0	1.2
21 May	3.3	1.9	8.2	4.6	7.5	4.2	8.2	4.6	7.4	2.5
21 June	4.0	2.3	8.6	4.7	6.9	3.9	8.6	4.6	8.2	3.0
23 July	3.3	1.8	8.1	4.5	7.6	4.2	8.1	4.5	7.4	2.5
24 August	2.1	1.2	6.8	3.8	8.6	4.8	6.8	3.8	5.0	1.2
22 September	1.5	0.8	5.0	2.8	9.1	5.0	5.0	2.8	2.4	- 0.2
16 October	1.1	0.6	3.5	1.9	8.4	4.7	3.5	1.9	0.4	- 1.4
15 November	0.6	0.3	1.9	1.0	6.2	3.5	1.9	1.0	- 1.6	- 2.5
16 December	0.4	0.2	1.3	0.7	5.0	2.7	1.3	0.7	- 2.2	- 2.8

	Northeast Northwest		Southeast Southwest			Cylinder		Hemispherical Cap	
	Dark	Light	Dark	Light		Dark	Light	Dark	Light
16 January	0.5	0.3	4.1	2.3	16 January	2.3	1.3	- 1.7	- 2.5
15 February	1.0	0.6	5.7	3.1	15 February	3.4	1.9	- 0.6	- 1.9
22 March	2.3	1.3	7.8	4.4	16 March	4.8	2.7	0.9	- 1.1
20 April	3.9	2.2	8.4	4.7	15 April	6.0	3.3	2.6	- 0.1
21 May	5.5	3.1	8.5	4.7	16 May	6.9	3.6	4.0	+ 0.7
21 June	6.3	3.5	8.3	4.6	15 June	7.2	4.0	4.6	0.9
23 July	5.5	3.1	8.5	4.7	16 July	7.1	3.9	4.3	0.8
24 August	3.9	2.2	8.4	4.7	16 August	6.4	3.7	3.3	0.1
22 September	2.3	1.3	7.9	4.4	15 September	5.4	3.0	1.7	0.7
16 October	1.4	0.8	6.5	3.6	16 October	4.1	2.3	0.1	- 1.6
15 November	0.7	0.4	4.6	2.5	15 November	2.7	1.5	- 1.3	- 2.4
16 December	0.4	0.2	3.7	2.0	16 December	2.2	1.1	- 1.9	- 2.8

Conical Caps	Base angle 27°		Base angle 37°		Base angle 45°		Base angle 56°	
	Dark	Light	Dark	Light	Dark	Light	Dark	Light
16 January	- 1.8	- 2.6	- 1.8	- 2.6	- 1.8	- 2.6	- 1.9	- 2.7
15 February	- 0.3	- 1.8	- 0.5	- 1.9	- 0.5	- 1.9	- 0.8	- 2.0
16 March	2.0	- 0.5	1.7	- 0.7	1.5	- 0.7	1.0	- 1.0
15 April	4.7	1.0	4.1	0.7	3.8	0.6	2.9	0.0
16 May	6.9	2.2	6.2	1.8	5.7	1.6	4.4	0.9
15 June	8.0	2.8	7.1	2.3	6.5	2.0	5.1	1.3
16 July	7.5	2.6	6.7	2.1	6.2	1.8	4.9	1.1
16 August	5.7	1.6	5.1	1.2	4.6	1.0	3.6	0.4
15 September	3.1	0.1	2.7	- 0.1	2.5	- 0.2	1.8	- 0.6
16 October	0.6	- 1.3	0.4	- 1.3	0.3	- 1.4	- 0.1	- 1.6
15 November	- 1.4	- 2.4	- 1.4	- 2.4	- 1.4	- 2.4	- 1.6	- 2.5
16 December	- 2.1	- 2.7	- 2.1	- 2.7	- 2.1	- 2.8	- 2.1	- 2.8

The base angle corresponds to radius = 2 x height; radius = 1¼ x height; radius = height; radius = ⅔ height

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Table I (continued)

Mean Sol-air Temperature Increments (TI)[1] for Sloping Roofs

	North		East		South		West		Northeast		Southeast		Southwest		Northwest		
	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	
16 Jan	- 2.7	- 3.1	- 2.0	- 2.7	- 1.3	- 2.3	- 2.0	- 2.7	- 2.5	- 3.0	- 1.5	- 2.4	- 1.5	- 2.4	- 2.5	- 3.0	)
15 Feb	- 1.6	- 2.5	- 0.6	- 2.0	+ 0.3	- 1.4	- 0.6	- 2.0	- 1.3	- 2.3	+ 0.1	- 1.6	+ 0.1	- 1.6	- 1.3	- 2.3	)
22 Mar	0.7	- 1.2	1.9	- 0.6	2.9	0.0	1.9	- 0.6	1.1	- 1.0	2.7	- 0.1	2.7	- 0.1	1.1	- 1.0	)
20 Apl	4.2	0.7	5.0	1.2	5.8	1.6	5.0	1.2	4.3	0.8	5.6	1.5	5.6	1.5	4.3	0.8	)
21 May	6.7	2.1	7.3	2.4	7.8	2.7	7.3	2.4	6.8	2.1	7.7	2.6	7.7	2.6	6.8	2.1	)
21 June	7.6	2.6	8.0	2.9	8.4	3.1	8.0	2.9	7.7	2.7	8.3	3.0	8.3	3.0	7.7	2.7	)
23 July	6.7	2.1	7.3	2.4	7.8	2.7	7.3	2.4	6.8	2.1	7.7	2.6	7.7	2.6	6.8	2.1	) 10° slope
24 Aug	4.2	0.7	5.0	1.2	5.8	1.6	5.0	1.2	4.3	0.8	5.6	1.5	5.6	1.5	4.3	0.8	)
23 Sept	0.7	- 1.2	1.9	- 0.6	2.9	0.0	1.9	- 0.6	1.1	- 1.0	2.7	- 0.1	2.7	- 0.1	1.1	- 1.0	)
16 Oct	- 0.7	- 2.0	+ 0.3	- 1.4	1.3	- 0.9	0.3	- 1.4	- 0.5	- 1.8	1.1	- 1.0	1.1	- 1.0	- 0.5	- 1.8	)
15 Nov	- 2.4	- 3.0	- 1.5	- 2.5	- 0.7	- 2.0	- 1.5	- 2.5	- 2.1	- 2.8	- 0.9	- 2.1	- 0.9	- 2.1	- 2.1	- 2.8	)
16 Dec	- 2.9	- 3.2	- 2.3	- 2.9	- 1.6	- 2.5	- 2.3	- 2.9	- 2.7	- 3.1	- 1.8	- 2.6	- 1.8	- 2.6	- 2.7	- 3.1	)
16 Jan	- 3.1	- 3.3	- 2.1	- 2.8	- 0.6	- 1.9	- 2.1	- 2.8	- 3.1	- 3.3	- 1.1	- 2.1	- 1.1	- 2.1	- 3.1	- 3.3	)
15 Feb	- 2.6	- 3.0	- 0.8	- 2.0	- 1.1	- 1.0	- 0.8	- 2.0	- 2.2	- 2.8	0.6	- 1.3	0.6	- 1.3	- 2.2	- 2.8	)
22 Mar	- 0.5	- 1.9	1.9	- 0.6	3.7	0.5	1.9	- 0.6	0.4	- 1.4	3.1	0.1	3.1	0.1	0.4	- 1.4	)
20 Apl	2.5	- 0.2	4.8	1.1	6.2	1.9	4.8	1.1	3.5	0.3	5.9	1.7	5.9	1.7	3.5	0.3	)
21 May	5.7	1.5	6.9	2.2	7.0	2.4	6.9	2.2	5.8	1.6	7.6	2.6	7.6	2.6	5.8	1.6	)
21 June	6.7	2.1	7.7	2.6	8.1	2.9	7.7	2.6	6.8	2.2	8.3	3.0	8.3	3.0	6.8	2.2	)
23 July	5.7	1.5	6.9	2.2	7.0	2.4	6.9	2.2	5.8	1.6	7.6	2.6	7.6	2.6	5.8	1.6	) 20° slope
24 Aug	2.5	0.2	4.8	1.1	6.2	1.9	4.8	1.1	3.5	0.3	5.9	1.7	5.9	1.7	3.5	0.3	)
23 Sept	- 0.5	- 1.9	1.9	- 0.6	3.7	0.5	1.9	- 0.6	0.4	- 1.4	3.1	0.1	3.1	0.1	0.4	- 1.4	)
16 Oct	- 1.8	- 2.6	0.3	- 1.4	2.2	- 0.4	0.3	- 1.4	- 1.2	- 2.1	1.5	- 0.8	1.5	- 0.8	- 1.2	- 2.1	)
15 Nov	- 3.0	- 3.3	- 1.8	- 2.6	- 0.1	- 1.7	- 1.8	- 2.6	- 3.0	- 3.3	- 0.6	- 1.9	- 0.6	- 1.9	- 3.0	- 3.3	)
16 Dec	- 3.1	- 3.3	- 2.4	- 2.9	- 1.1	- 2.2	- 2.4	- 2.9	- 3.1	- 3.3	- 1.5	- 2.4	- 1.5	- 2.4	- 3.1	- 3.3	)
16 Jan	- 3.1	- 3.3	- 2.1	- 2.7	- 0.1	- 1.6	- 2.1	- 2.7	- 3.1	- 3.3	- 0.7	- 2.0	- 0.7	- 2.0	- 3.1	- 3.3	)
15 Feb	- 2.8	- 3.1	- 0.9	- 2.1	1.8	- 0.5	- 0.9	- 2.1	- 2.7	- 3.1	1.0	- 1.0	1.0	- 1.0	- 2.7	- 3.1	)
22 Mar	- 1.7	- 2.6	1.7	- 0.6	4.3	0.8	1.7	- 0.6	- 0.6	- 0.9	3.2	0.2	3.2	0.2	- 0.6	- 1.9	)
20 Apl	0.7	- 1.2	4.5	0.9	6.6	2.1	4.5	0.9	2.5	0.2	5.9	1.7	5.9	1.7	2.5	- 0.2	)
21 May	4.5	0.9	6.6	2.0	7.0	2.3	6.6	2.0	4.9	1.2	7.6	2.6	7.6	2.6	4.9	1.2	)
21 June	5.6	1.5	7.2	2.4	7.2	2.4	7.2	2.4	5.8	1.7	7.8	2.8	7.8	2.8	5.8	1.7	)
23 July	4.5	0.9	6.6	2.0	7.0	2.3	6.6	2.0	4.9	1.2	7.6	2.6	7.6	2.6	4.9	1.2	) 30° slope
24 Aug	0.7	- 1.2	4.5	0.9	6.6	2.1	4.5	0.9	2.5	0.2	5.9	1.7	5.9	1.7	2.5	- 0.2	)
23 Sept	- 1.7	- 2.6	1.7	- 0.6	4.3	0.8	1.7	- 0.6	- 0.6	- 0.9	3.2	0.2	3.2	0.2	- 0.6	- 1.9	)
16 Oct	- 2.8	- 3.1	0.2	- 1.5	2.8	0	0.2	- 1.5	- 2.2	- 2.9	1.9	- 0.6	1.9	- 0.6	- 2.2	- 2.9	)
15 Nov	- 3.0	- 3.3	- 1.8	- 2.6	0.5	- 1.3	- 1.8	- 2.6	- 3.0	- 3.3	- 0.2	- 1.6	- 0.2	- 1.6	- 3.0	- 3.3	)
16 Dec	- 3.1	- 3.3	- 2.3	- 2.9	- 0.5	- 1.9	- 2.3	- 2.9	- 3.1	- 3.3	- 1.0	- 2.2	- 1.0	- 2.2	- 3.1	- 3.3	)

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Table II

Approximate Solar Times of Maximum Heat Input into Buildings

Area of Faces	Square Equal N-E-S-W	Equal NE-SE-SW-NW	Rectangular with sides in 2:1 ratio				Cylindrical with conical or hemispherical roof
			2N and S 1E and W	2E and W 1N and S	2NE and SW 1NW and SE	2NW and SE 1NE and SW	
16 January	1300	1200	1300	1300	1200	1200	1200
15 February	1400	1200	1300	1400	1200	1200	1200
22 March	1400	1300	1400	1500	1300	1200	1200
20 April	1400	1500	1400	1500	1500	1200	1400
21 May	1400	1500	1400	1500	1500	1600	1500
21 June	1400	1600	1400	1500	1500	1600	1500
23 July	1400	1500	1400	1500	1500	1600	1500
24 August	1400	1500	1400	1500	1500	1200	1400
22 September	1400	1300	1400	1500	1300	1200	1300
16 October	1400	1200	1300	1500	1300	1200	1200
15 November	1300	1200	1300	1300	1200	1200	1200
16 December	1300	1200	1200	1300	1200	1200	1200

Table III

'Swing' of TI from mean to value at listed times for vertical surfaces

Month	Time	North		East		South		West		Horizontal		North East		South East		South West		North West	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
16 January	1200	1.9	1.0	0.9	0.4	20.1	11.1	0.9	0.4	6.4	3.7	1.8	1.0	14.9	8.2	14.9	8.2	1.8	1.0
	1300	1.7	0.9	0.7	0.3	18.4	10.2	6.4	3.5	5.6	3.2	1.6	0.9	9.4	5.2	17.6	9.8	1.6	0.9
15 February	1200	2.4	1.3	0.5	0.4	22.4	12.4	0.5	0.4	9.4	5.2	2.2	1.2	16.3	9.0	16.3	9.0	2.2	1.2
	1300	2.1	1.2	0.2	0.2	20.7	11.5	7.4	4.1	8.7	4.8	1.9	1.1	9.5	5.5	20.6	11.3	1.9	1.1
	1400	1.8	1.0	0.0	0.0	16.4	9.1	12.8	7.1	6.5	3.6	1.6	0.9	2.9	1.6	21.1	11.7	1.6	0.9
22 March & 22 September	1200	3.0	1.6	0.4	0.2	22.2	12.4	0.4	0.2	14.0	7.8	2.1	1.1	16.5	9.1	16.5	9.1	2.1	1.1
	1300	2.9	1.6	- 0.7	- 0.4	20.7	11.5	8.1	4.5	13.6	7.5	2.0	1.1	9.1	5.0	21.2	11.7	2.0	1.1
	1400	2.6	1.4	- 1.0	- 0.6	17.1	9.5	15.5	8.6	10.3	6.2	1.7	0.9	0.3	0.1	24.2	13.4	1.7	0.9
	1500	1.8	1.0	- 1.8	- 1.0	10.7	6.0	20.0	11.1	7.2	4.0	0.9	0.5	- 4.6	- 2.6	22.6	12.5	3.7	2.0
20 April & 24 August	1200	3.3	1.8	- 0.6	- 0.4	20.7	11.5	- 0.6	- 0.4	10.9	9.4	1.4	0.8	13.9	7.7	13.9	7.7	1.4	0.8
	1300	3.2	1.7	- 1.6	- 0.9	19.4	10.7	7.8	4.3	16.1	9.1	1.3	0.7	6.0	3.3	19.4	10.7	1.3	0.7
	1400	2.8	1.5	- 2.0	- 1.1	15.7	8.7	15.9	8.8	13.8	7.7	0.9	0.5	- 1.5	- 1.0	22.5	12.5	1.1	0.6
	1500	2.3	1.2	- 2.5	- 1.4	10.5	5.8	20.8	11.5	10.4	5.7	0.4	0.2	- 4.1	- 2.3	22.4	12.4	6.9	3.8
21 May & 23 July	1400	2.6	1.4	- 2.3	- 1.3	13.6	7.5	14.8	8.3	15.0	8.4	0.4	0.2	- 2.6	- 1.4	20.3	11.3	0.8	0.4
	1500	1.4	0.7	- 3.5	- 2.0	8.2	4.5	20.2	11.3	11.4	6.4	- 0.8	- 0.5	- 3.8	- 2.1	21.0	11.8	8.5	4.8
	1600	0.6	0.3	- 4.3	- 2.4	1.5	0.8	22.5	12.5	7.0	3.8	- 1.6	- 0.9	- 4.6	- 2.5	18.5	10.3	13.8	7.7
21 June	1400	1.4	0.9	- 3.2	- 1.5	12.1	6.8	14.1	7.8	15.6	8.9	- 1.1	- 0.3	- 2.9	- 1.4	19.0	10.7	1.4	0.5
	1500	0.7	0.5	- 3.9	- 1.9	6.8	3.7	19.4	11.0	12.1	6.6	- 1.8	- 0.7	- 3.6	- 1.8	20.3	11.2	9.0	4.8
	1600	0.3	0.0	- 4.3	- 2.4	0.8	0.4	22.4	12.4	7.6	4.2	- 2.2	- 1.2	- 4.0	- 2.3	18.4	10.2	14.7	8.3
16 October	1200	2.6	1.4	0.2	0.1	22.6	12.6	0.2	0.1	11.1	6.1	2.3	1.2	16.2	9.0	16.2	9.0	2.3	1.2
	1300	2.4	1.3	0.0	0.0	21.1	11.8	7.7	4.3	10.2	5.6	2.1	1.1	9.8	5.4	21.0	11.6	2.1	1.1
	1400	2.0	1.1	- 0.4	- 0.2	16.9	9.5	13.7	7.6	8.0	4.5	1.7	0.9	2.2	1.2	22.4	12.4	1.7	0.9
	1500	1.3	0.7	- 1.1	- 0.6	9.9	5.5	16.5	9.1	4.5	2.5	1.0	0.5	- 4.1	2.3	19.6	10.9	2.2	1.2
15 November	1200	1.9	1.1	0.6	0.4	21.0	11.6	0.6	0.4	7.2	4.0	1.8	1.0	15.4	8.5	15.4	8.5	1.8	1.0
	1300	1.8	1.0	0.5	0.3	19.3	10.7	9.2	5.1	6.5	3.6	1.7	0.9	9.6	5.4	18.5	10.3	1.7	0.9
16 December	1200	1.7	1.0	0.8	0.5	19.1	10.7	0.8	0.5	5.5	3.0	1.7	1.0	14.0	7.8	14.0	7.8	1.7	1.0
	1300	1.4	0.8	0.5	0.3	17.0	9.5	5.7	3.2	5.0	2.8	1.4	0.8	9.0	5.1	16.3	9.1	1.4	0.8

Table III continued

Swing of TI from mean to value at listed times
Sloping Surfaces

10° Slope

Month	Solar Time	North		East		South		West		North East		South East		South West		North West	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
16 January	1200	3.7	2.1	6.4	3.5	9.1	4.9	6.4	3.5	4.6	2.5	8.2	4.5	8.2	4.5	4.6	2.5
	1300	3.4	1.8	4.9	2.6	8.0	4.4	6.5	3.6	3.5	1.9	6.8	3.7	7.9	4.3	4.6	2.5
15 February	1200	6.6	3.6	9.3	5.2	12.1	6.7	9.3	5.2	7.4	4.0	11.2	6.3	11.2	6.3	7.4	4.0
	1300	6.1	3.4	7.6	4.4	11.3	6.1	9.6	5.4	6.1	3.3	9.7	5.4	11.1	6.2	7.5	4.1
	1400	4.4	2.5	4.6	2.6	8.5	4.6	9.4	5.2	3.7	2.0	6.5	3.7	9.1	5.1	6.3	3.4
22 March & 22 September	1200	11.5	6.4	14.1	7.9	16.9	9.4	14.1	7.9	12.2	6.8	16.0	8.9	16.0	8.9	12.2	6.8
	1300	10.4	5.7	11.6	6.4	15.4	8.5	14.0	7.8	10.3	5.6	13.7	7.5	15.8	8.5	11.9	6.6
	1400	9.4	5.1	9.0	4.5	13.3	7.3	13.4	7.4	8.2	4.5	11.0	6.0	14.2	7.8	11.4	6.3
	1500	6.1	3.4	4.3	2.5	8.3	4.6	9.9	5.5	4.4	2.5	5.9	3.7	9.8	5.4	8.3	4.6
20 April & 24 August	1200	13.9	7.7	16.4	9.1	18.9	10.6	16.4	9.1	14.7	8.2	18.2	10.1	18.2	10.1	14.7	8.2
	1300	13.6	7.6	14.6	8.1	18.2	10.1	17.2	9.5	13.5	7.5	16.6	9.2	18.4	10.2	15.3	8.5
	1400	11.6	6.5	11.1	6.2	15.4	8.6	15.9	8.8	10.6	5.9	13.1	7.3	16.5	9.2	14.0	7.8
	1500	8.9	4.9	6.8	3.7	11.1	6.2	13.2	7.3	7.0	3.9	8.5	4.7	13.1	7.2	9.8	5.4
21 May & 23 July	1400	13.4	7.4	12.7	7.0	16.7	9.2	17.3	9.6	12.3	6.8	14.7	8.0	17.8	9.9	15.6	8.7
	1500	10.3	5.8	7.9	4.5	12.2	6.8	14.5	8.1	8.3	4.7	9.6	5.4	14.2	8.0	12.9	7.3
	1600	6.8	3.7	3.2	1.7	7.1	3.9	10.6	5.9	4.3	2.3	4.4	2.4	9.6	5.4	9.5	5.3
21 June	1400	13.5	7.5	12.7	7.0	16.5	9.2	17.5	9.4	12.3	6.8	14.5	8.1	17.9	9.9	15.4	8.6
	1500	10.7	6.0	8.1	4.7	12.7	7.1	14.9	8.3	8.8	4.9	10.1	5.7	14.6	8.2	13.3	7.4
	1600	7.1	4.0	3.6	1.9	7.5	4.2	11.0	6.1	4.6	2.5	4.8	2.7	10.0	5.6	9.8	5.4
16 October	1200	8.2	4.5	10.9	6.0	13.7	7.6	10.9	6.0	8.9	4.9	12.9	7.1	12.9	7.1	8.9	4.9
	1300	7.5	4.2	9.7	4.8	12.6	7.1	11.1	6.4	7.4	4.1	11.1	6.2	12.6	7.1	8.9	5.0
	1400	5.8	3.3	5.9	3.3	10.0	5.6	9.9	5.5	5.0	2.8	8.0	4.4	10.8	6.0	7.8	4.4
	1500	3.3	1.8	2.0	1.0	5.7	3.1	7.0	3.8	2.0	1.0	3.9	1.9	7.0	3.8	5.1	2.9
15 November	1200	4.5	2.4	7.0	3.9	9.6	5.4	7.0	3.9	5.2	2.8	8.8	4.9	8.8	4.9	5.2	2.8
	1300	4.0	2.1	5.4	3.0	8.7	4.8	7.2	4.0	4.4	2.2	7.3	4.0	8.6	4.7	5.5	2.9
16 December	1200	3.1	1.7	5.6	3.1	8.0	4.4	5.6	3.1	3.8	2.1	7.3	4.0	7.3	4.0	3.8	2.1
	1300	2.7	1.4	4.1	2.3	7.0	3.9	5.7	3.1	2.8	1.5	5.9	3.2	6.9	3.8	3.8	2.1

Table III continued

Swing of TI from mean to value at listed times
Sloping Surfaces

20° Slope

Month	Solar Time	North		East		South		West		North East		South East		South West		North West	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
16 January	1200	1.6	0.9	6.2	3.5	11.1	6.1	6.2	3.5	1.6	0.9	9.7	5.3	9.7	5.3	1.6	0.9
	1300	1.5	0.8	0.5	0.3	10.1	5.5	7.2	4.0	1.5	0.8	7.7	4.1	9.9	5.4	1.5	0.8
15 February	1200	3.5	1.9	9.0	5.0	14.4	8.1	9.0	5.0	5.2	2.9	12.8	7.2	12.8	7.2	5.2	2.9
	1300	3.2	1.8	6.3	3.5	13.3	7.4	10.3	5.7	3.4	1.9	10.4	5.8	13.2	7.4	6.2	3.5
	1400	1.2	0.6	- 0.6	- 0.4	10.1	5.6	8.1	1.3	0.8	0.4	6.4	3.6	11.4	6.4	0.8	0.4
22 March & 22 September	1200	8.3	4.6	13.3	7.4	18.9	10.4	13.3	7.4	9.6	5.3	17.3	9.6	17.3	9.6	9.6	5.3
	1300	7.4	4.1	9.7	5.3	17.4	9.5	14.5	8.1	6.9	3.7	14.3	7.8	17.6	9.8	10.3	5.7
	1400	6.8	3.8	6.1	3.4	14.8	8.2	14.9	8.4	4.6	2.6	10.5	5.9	16.7	9.5	10.8	6.0
	1500	4.8	2.6	1.1	0.7	9.0	5.0	12.1	6.7	1.3	0.7	4.5	2.7	15.2	6.8	9.0	5.0
20 April & 24 August	1200	11.4	6.3	15.7	8.7	20.9	11.6	15.7	8.7	12.3	6.9	19.3	10.7	19.3	10.7	12.3	6.9
	1300	11.3	6.3	12.7	7.0	20.0	11.1	17.7	9.8	10.4	5.8	16.7	9.2	20.2	11.2	13.9	7.8
	1400	9.9	5.5	8.2	4.5	16.8	9.2	17.6	9.7	7.2	4.0	12.2	6.7	18.8	10.4	13.8	7.7
	1500	8.0	4.4	3.1	1.6	11.9	6.5	15.9	8.8	3.6	2.0	6.6	3.6	15.6	8.6	12.6	7.0
21 May & 23 July	1400	11.3	6.3	9.8	5.4	18.6	10.2	19.0	10.6	9.2	5.1	13.5	7.5	20.0	11.1	15.7	8.7
	1500	9.0	5.1	4.4	2.4	13.7	7.4	17.2	9.6	5.2	2.9	7.7	4.3	16.8	9.3	14.3	7.9
	1600	6.4	3.6	- 0.7	- 0.4	7.9	4.3	13.9	7.8	1.5	0.9	1.6	1.0	12.1	6.7	11.9	6.6
21 June	1400	11.5	6.1	9.7	5.1	17.9	9.7	19.1	10.3	9.3	4.8	13.3	7.1	19.8	10.8	15.8	8.5
	1500	9.5	5.3	4.8	2.8	13.5	7.5	17.6	9.8	5.7	3.1	8.0	4.5	17.0	9.5	14.7	8.1
	1600	6.6	3.6	- 0.5	- 0.3	7.6	4.2	14.1	7.9	1.7	0.8	1.9	1.0	12.2	6.8	12.0	6.6
16 October	1200	5.1	2.7	10.4	5.7	16.0	8.9	10.4	5.7	6.6	3.5	14.5	8.0	14.5	8.0	6.6	3.5
	1300	4.6	2.5	7.4	3.6	14.8	8.3	11.8	7.0	4.6	2.3	11.9	6.6	14.9	8.4	7.6	4.1
	1400	3.5	2.0	3.6	2.0	11.7	6.6	11.4	6.4	1.9	1.0	7.8	4.5	13.4	7.5	7.5	4.0
	1500	1.9	1.0	- 0.7	- 0.4	6.7	3.8	9.1	5.0	- 0.9	- 0.6	2.7	1.5	9.6	5.3	6.0	3.2
15 November	1200	1.6	0.9	7.0	3.8	11.9	6.7	7.0	3.8	1.6	0.9	10.5	5.8	10.5	5.8	1.6	0.9
	1300	1.6	0.9	0.5	0.2	10.9	6.1	7.8	4.4	1.6	0.9	8.3	4.6	10.7	5.9	1.6	0.9
16 December	1200	1.5	0.8	6.5	2.9	10.2	5.5	6.5	2.9	1.5	0.8	8.8	4.8	8.8	4.8	1.5	0.8
	1300	1.4	0.8	0.7	0.4	9.0	5.0	7.5	3.4	1.4	0.8	6.8	3.7	8.8	4.8	1.4	0.8

Table III continued

Swing of TI from mean to value at listed times
Sloping Surfaces

30° Slope

Month	Solar Time	North		East		South		West		North East		South East		South West		North West	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
16 January	1200	1.6	0.9	5.8	3.1	13.1	7.1	5.8	3.1	1.6	0.9	11.0	6.0	11.0	6.0	1.6	0.9
	1300	1.5	0.8	0.5	0.2	11.9	6.6	7.5	4.1	1.5	0.8	8.3	4.6	11.6	6.4	1.5	0.8
15 February	1200	1.7	1.0	8.4	4.7	16.4	9.0	8.4	4.7	1.6	1.0	14.0	7.8	14.0	7.8	1.6	1.0
	1300	1.6	0.9	- 0.3	- 0.1	15.2	8.3	10.7	5.9	1.5	0.9	11.0	6.1	15.1	8.3	1.5	0.9
	1400	1.4	0.7	- 0.5	- 0.3	11.6	6.3	10.9	6.1	1.3	0.7	6.3	3.4	13.6	7.4	1.3	0.7
22 March	1200	4.9	2.8	12.3	6.8	20.5	11.4	12.3	6.8	6.9	3.8	18.5	10.3	18.5	10.3	6.9	3.8
&	1300	4.2	2.4	7.6	4.1	18.8	10.4	14.6	8.1	3.5	1.9	14.4	8.0	19.5	10.8	8.6	4.7
22 September	1400	4.1	2.4	3.1	1.7	15.9	8.8	16.1	8.9	1.1	0.6	9.8	5.4	18.9	10.5	10.2	5.7
	1500	0.6	0.4	- 2.8	- 1.6	9.6	5.4	14.1	7.8	- 0.5	- 0.3	- 4.3	- 2.4	14.5	8.0	9.7	5.3
20 April	1200	8.6	4.8	14.4	8.0	21.9	12.1	14.4	8.0	9.6	5.3	19.8	11.0	19.8	11.0	9.6	5.3
&	1300	8.6	4.8	10.2	5.8	20.9	11.6	17.6	9.8	7.0	4.0	16.3	9.1	21.4	11.9	12.1	6.8
24 August	1400	7.8	4.4	4.8	2.7	17.3	9.7	18.6	10.4	3.4	2.0	10.8	6.1	20.6	11.5	13.2	7.4
	1500	6.8	3.8	- 0.7	- 0.4	12.1	6.7	17.9	10.0	0.1	0.0	4.5	2.5	17.7	9.9	13.3	7.4
21 May	1400	8.9	4.9	6.4	3.5	19.0	10.5	19.8	11.1	5.5	3.0	11.8	6.5	21.4	11.8	15.1	8.3
&	1500	7.4	4.1	0.2	0.3	13.5	7.5	19.0	10.7	1.6	0.9	5.1	3.0	18.5	10.3	14.8	8.2
23 July	1600	5.7	3.3	- 5.0	- 2.7	7.4	4.1	16.4	9.3	- 1.7	- 1.0	- 1.4	- 0.7	13.8	7.7	13.5	7.5
21 June	1400	9.1	5.0	6.4	3.6	18.9	10.5	20.0	11.0	5.8	3.1	11.8	6.4	21.4	11.8	15.4	8.5
	1500	7.8	4.4	0.8	0.6	14.0	7.9	19.4	10.8	2.2	1.2	5.7	3.2	18.8	10.5	15.3	8.5
	1600	5.0	3.4	- 4.6	- 2.5	7.8	4.3	16.8	9.3	- 1.2	- 0.8	- 0.8	- 0.5	14.2	7.9	13.8	7.6
16 October	1200	1.9	1.0	9.6	5.3	17.9	9.9	9.6	5.3	1.3	0.8	15.7	8.7	15.7	8.7	1.3	0.8
	1300	1.9	1.0	5.6	2.5	16.7	9.2	12.0	6.6	1.3	0.8	12.4	6.9	16.8	9.3	1.3	0.8
	1400	1.7	0.9	1.2	0.7	13.2	7.3	12.6	7.1	1.1	0.7	7.5	4.3	15.6	8.7	6.7	3.8
	1500	1.4	0.7	- 1.6	- 0.9	7.6	4.1	10.9	6.0	0.8	0.5	3.2	1.8	11.7	6.5	4.5	2.7
15 November	1200	1.6	0.9	6.4	3.6	14.0	8.2	6.4	3.6	1.6	0.9	11.7	6.5	11.7	6.5	1.6	0.9
	1300	1.6	0.9	0.4	0.2	12.7	7.0	7.9	4.5	1.6	0.9	8.9	4.9	12.5	6.8	1.6	0.9
16 December	1200	1.5	0.8	5.0	2.7	11.5	6.6	5.0	2.7	1.5	0.8	9.9	5.5	9.9	5.5	1.5	0.8
	1300	1.4	0.8	0.6	0.4	10.6	5.9	6.5	3.5	1.4	0.8	7.3	4.1	10.1	5.7	1.4	0.8

Table III (continued)

'Swing' of TI from mean to value at listed times

Month	Time	Cylinder		Cone 27°		Cone 37°		Cone 45°		Cone 56°		Hemisphere	
		D	L	D	L	D	L	D	L	D	L	D	L
16 January	1200	7.5	4.1	7.0	3.8	6.8	3.7	6.6	3.7	6.1	3.4	6.4	3.5
15 February	1200	8.3	4.6	9.6	5.4	9.3	5.2	8.9	4.9	8.0	4.4	7.8	4.3
16 March	1200	8.1	4.5	13.1	7.3	12.2	6.8	11.5	6.4	9.9	5.5	9.0	5.1
15 April	1400	7.2	4.1	12.8	7.1	11.8	6.5	11.1	6.1	9.5	5.3	8.4	4.7
16 May	1500	6.2	3.4	11.1	6.1	10.1	5.6	9.5	5.3	8.3	4.6	7.2	4.2
15 June	1500	5.9	3.3	11.2	6.2	10.4	5.8	9.7	5.4	8.4	4.6	7.2	4.1
16 July	1500	6.0	3.3	11.3	6.2	10.5	5.7	9.7	5.4	8.3	4.6	7.3	4.1
16 August	1400	6.7	3.6	13.5	7.4	12.4	6.9	11.6	6.4	9.9	5.5	8.5	4.9
15 September	1300	7.8	4.3	13.7	7.7	12.6	7.0	11.9	6.6	10.1	5.7	9.1	5.1
16 October	1200	8.2	4.6	11.2	6.2	10.5	5.8	10.0	5.6	8.9	4.9	8.3	4.6
15 November	1200	7.7	4.3	7.4	4.2	7.4	4.1	7.1	4.1	6.6	3.7	6.8	3.9
16 December	1200	7.1	4.0	6.2	3.4	6.0	3.3	6.0	3.3	5.7	3.1	5.9	3.4

Table IV

Variation of R_{so} with type of surface and exposure
(as given in IHVE guide table A.3.5)

	Emissivity of Surface	Exposure		
		Sheltered	Standard	Severe
Wall	High	0.08	0.055	0.03
	Low	0.11	0.067	0.03
Roof	High	0.07	0.045	0.02
	Low	0.09	0.053	0.02
Corresponding wind speed ms^{-1}		2-3.5	4-5.5	6-7.5

Table V

Simplified ratios between adopted values for R_{so} for a standard exposure and a surface of high emissivity and other exposures and surfaces

	Emissivity of Surface	Exposure		
		Sheltered	Standard	Severe
Wall adopted value 0.05	High	1.6	1	0.6
	Low	2.2	1.3	0.6
Roof adopted value 0.04	High	1.75	1	0.5
	Low	2.25	1.3	0.5

Table VI

Infiltration Rates (N) per hour

Volume of Building	Unlined Sheet Construction	Single Storey or Unpartitioned	Curtain Wall or Sheet Lined
Up to 300 m^3	$2\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$
300 to 3,000 m^3	$1\frac{1}{2}$	$\frac{3}{4}$	1
3,000 to 10,000 m^3	1	$\frac{1}{2}$	$\frac{3}{4}$
Over 10,000 m^3	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{2}$

Multi Storey

Lower floor	1
Intermediate floor	1
Top floor with flat roof	1
Top floor with sheet lined roof	$1\frac{1}{4}$
Top floor with sheeted unlined roof	$1\frac{1}{2}$